AD-A257 253

(12)

Chase Inc.

87 Summer Street, Suite 510
Boston, MA 02110
(617) 350-7633

TURBULENT BOUNDARY-LAYER FLUCTUATIONS AT THE SOLID INTERFACE

Chase Inc. CR 93-01

24 September 1992

Chase Inc. Job No. 068

Final Report

Contract no. N00014-88-C-0673

Sequence no. A002

Submitted to:

Dr. L. Patrick Purtell, Code 1132F
Scientific Officer
Fluid Dynamics Program
Mechanics Division
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT:

4. PERFORMING ORGANIZATION REPORT NUMBER(S): CHASEINC/CR9301 (ONR)

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Chase Inc.

6b. OFFICE SYMBOL (If applicable):

6c. ADDRESS (City, State, and ZIP Code):
87 Summer Street, Suite 510
Boston, MA 02110

7a. NAME OF MONITORING ORGANIZATION:

7b. ADDRESS (City, State, and ZIP Code):

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Office of Naval Research

8b. OFFICE SYMBOL (If applicable): Code 1132F

8c. ADDRESS (City, State, and ZIP Code):
800 North Quincy Street
Arlington, VA 22217-5000

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification): TURBULENT BOUNDARY-LAYER FLUCTUATIONS AT THE SOLID INTERFACE

12. PERSONAL AUTHOR(S): D.M. Chase

13a. TYPE OF REPORT: Final

13b. TIME COVERED: FROM ______ TO ______

14. DATE OF REPORT (Year, Month, Day): 24 September 1992

15. PAGE COUNT: 7

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number):
turbulent boundary layer
fluctuating pressure
fluctuating shear stress
viscous boundary conditions

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A bibliography and brief indication of accomplishments under the subject contract is presented along with appended reprints of published papers to date.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: David M. Chase

22b. TELEPHONE (Include Area Code): (617) 350-7633

22c. OFFICE SYMBOL:

Introduction

The present document constitutes a formal final report on work by Chase Inc. funded by ONR under the Accelerated Research Initiative (ARI) on Solid/Fluid Interfaces. Summary information that follows here is based mainly on the ARI report by Chase Inc. submitted June 30, 1992.

Among papers listed below as published is one (numbered 3) where final mechanical revisions and publication are still in progress.

Item 2 of listed reports not otherwise published is being submitted separately. It includes certain work carried beyond that of the present contractual funding. A shorter version of it may be subsequently submitted for consideration for publication.

All of the cited items are incorporated in this final report by reference. Reprints of the published papers (with errata) are appended as available.

Significant presentations

1. 122nd Meeting of the Acoustical Society of America (invited paper), 4-8 November 1991, "Recent results regarding turbulent wall pressure and shear stress in boundary-layer flow and the role of the viscous wall condition;" abstract: *J. Acoust. Soc. Amer.* **90,** 2284 (1991).

   A history of questions and contrasting conceptions of the role of the viscous wall condition for the description of turbulent boundary-layer noise production was noted as a setting and focus for a presentation of related results of the present program, which clarify some issues but leave others open.

2. 1988 International Symposium on Flow-Induced Vibration and Noise (ASME), 27 November–2 December 1988, "The linearized approach to interaction of the inner turbulent boundary layer with a compliant wall as a possible guide to reduction of turbulence and flow noise;" published in the Proceedings, V. 6, *Acoustic phenomena and interaction in shear flows over compliant and vibrating surfaces.*

The possible utility of renewed development of a linearized approach for such purposes was outlined. This would regard the turbulent excitation as given in some form and calculate the boundary-layer response by linear dynamic equations for wave amplitudes. Further insight gleaned during the present program encourages hope from further development along these lines.

(Presentations at annual ONR program reviews are omitted here.)

Published papers *(reprints appended where available)*

1. D.M. Chase 1991 Fluctuations in wall-shear stress and pressure at low streamwise wavenumbers in turbulent boundary-layer flow. *J. Fluid Mech.,* **225,** 545-555.

   Significance resides especially in the following results, demonstrated under a certain (recently questioned) primary presumption. In incompressible turbulent boundary-layer flow, in the low-wavenumber domain important for flow-noise applications, fluctuating pressure and wall-shear stress are coherent and equal in spectral density. The dominant contribution to pressure as well as shear stress there is associated with imposition of the proper viscous wall condition, i.e. missed in the usual analytical description based on inviscid flow.

2. D.M. Chase 1992 Fluctuating wall-shear stress and pressure at low streamwise wavenumbers in turbulent boundary-layer flow at low Mach numbers. *J. Fluids and Strucs* . **6,** 395-413.

   Significantly, when the above work was generalized to slightly incompressible flow, the additional source terms that might have further enhanced low-wavenumber, including radiated, turbulent boundary-layer pressure proved negligible. A plausible model of the boundary-layer "sources" of fluctuating pressure and shear stress yields low-wavenumber spectra of these which, though depending on the viscous variable, may well exhibit a broad range of approximation by the scale-independent, wavevector-white form that accords with most measurements; these spectra may have, as well, a suitable level, thereby explaining those results.

3. D.M. Chase 1992 A semiempirical model for the wavevector-frequency spectrum of turbulent wall-shear stress. *J. Fluids and Strucs.*, in publication.

The first explicit proposed trial model of the wavevector- frequency spectral density of the streamwise component of turbulent wall-shear stress was formulated by analysis and fitting of previously measured partial spectra of fluctuating velocity, guided also by analytical considerations and modeling from the papers listed above. This model, subject to more comprehensive validation, supports applications to flow noise and other systems response where shear stress may play a role. It also provides guidance and focus for experimental and computational investigations of boundary-layer structure.

4. D.M. Chase 1991 Generation of fluctuating normal stress in a viscoelastic layer by surface shear stress and pressure as in turbulent boundary-layer flow. *J. Acoust. Soc. Amer.* **89**, 2589-2596.

Turbulent wall-shear stress at low wavenumbers, indicated above to be of a level similar to that of wall pressure, is shown to be converted into *normal* stress within an elastic solid layer bounding the flow. Calculated results in a representative configuration of this kind yields a corresponding transfer amplitude that, in an appreciable low-wavenumber range, exceeds that from wall *pressure*. Hence, significantly, turbulent wall- shear stress may be a substantial contributing source of self noise in some conformal, hull-mounted sonar arrays.

5. D.M. Chase 1991 The wavevector-frequency spectrum of pressure on a smooth plane in turbulent boundary-layer flow at low Mach number. *J. Acoust. Soc. Amer.* **90**, 1032-1040.

This paper, based on an invited presentation at a meeting of the Acoustical Society of America (1988) and funded under the present program only at the publication stage, provided a critical, comprehensive account of the then current status of the description of the wavevector-frequency spectrum of wall pressure beneath a canonical turbulent boundary layer. It is potentially useful especially in dispelling misconceptions and identifying unresolved issues.

Reports and memoranda not encompassed by cited published papers and presentations

1. "Fluctuations in wall-shear stress and pressure at low streamwise wavenumbers in turbulent boundary-layer flow," Chase Inc. TM 74 (1991). (This technical memorandum constitutes an earlier, more detailed version of published paper 1 above.)

2. "Fluctuations in wall pressure and shear stress at subconvective streamwise wavenumbers in turbulent boundary-layer flow," Chase Inc. TM 73 (24 September 1992).

Accomplishments

Analyzed relations of low-wavenumber fluctuating wall stresses to their Reynolds-stress "sources" in a turbulent boundary layer with application of properly viscous boundary conditions; proposed thereby a consistent account of the character of wall shear-stress and pressure spectra at low wavenumbers. [*J. Fluid Mech.* **225,** 545 (1991); *J. Fluids and Strucs.* **6** (1992)]. Extended results to higher subconvective wavenumbers [Chase Inc. TM 73, 24 September 1992].

Analyzed experimental results with guidance from theoretical considerations to evolve a semiempirical model of the wavevector- frequency spectral density of streamwise turbulent wall-shear stress encompassing both the convective and low-wavenumber domains. [*J. Fluids and Strucs.*, in publication (1992)]

Investigated the transfer from fluctuating wall-shear stress and pressure to normal stress within flow-bounding elastic media and its dependence on configuration variables, with a view to layer-embedded, conformal, hull-mounted sonar arrays. [*J. Acoust. Soc. Amer.* **89,** 2589 (1991)]

Stimulated research area; related accomplishments

Further application of the dynamic equations for wavevector- frequency amplitudes of boundary-layer fluctuations, regarded as linear with nonlinear

velocity-product amplitudes as sources, receives a stimulus from the insight derived in the present instance restricted to low wavenumbers. Assumption of trial forms for a phenomenological turbulent viscosity in this formulation, together with suitable restriction of the assumed source amplitude, are suggested to pursue development of a model Green's function for boundary-layer response in resonant-wave terms. This would encompass the convective domain that dominates the dynamic behavior and perhaps provide a useful approach to elucidating the response, including the transient response to a change in wall compliance or mean pressure gradient.

The work relating turbulent wall-shear stress and pressure at low wavenumbers to their sources in planar geometry was extended, under sponsorship of the (now) Naval Undersea Warfare Center, New London Branch (Dr. D. A. Hurdis), to the case of parallel flow along a cylinder, with application to self noise in towed arrays [Chase Inc. TM 70, May 1990 (Confidential)].